Robot for Remote Catheter Guidance through Blood Vessel Models

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Background

- The Bioengineering Devices Lab researches stroke treatment in blood vessels
- Research involves use of x-rays
- Project Goal: design, build, and test a robotic system that can translate and rotate a catheter into a benchtop vessel model remotely
- Budget: $5000
- Sponsor: Dr. Tim Becker

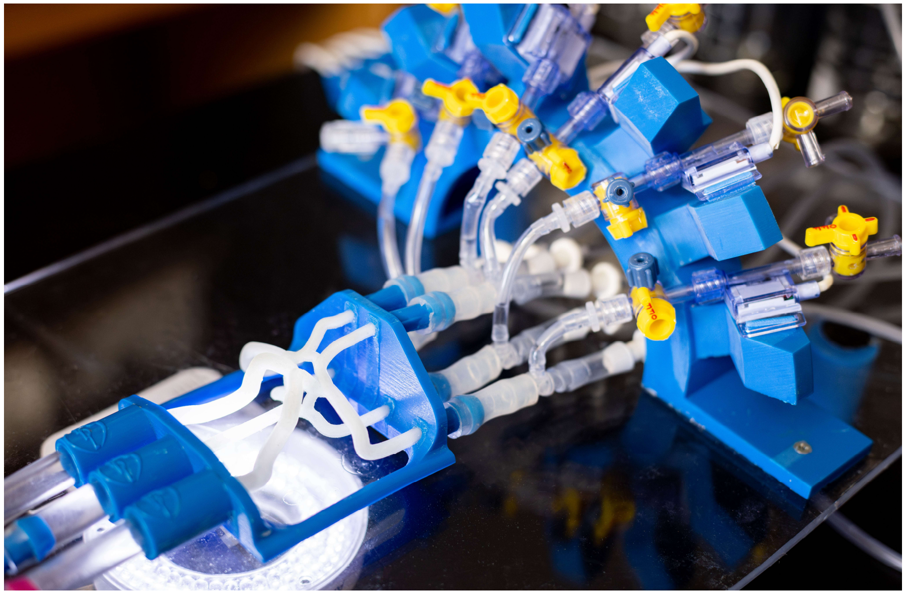


Figure 1. In vitro Circle of Willis blood vessel model attached to pressure sensors [1]

Customer Requirements

- CR1: Translation and rotation of catheter
- CR2: Pre-programmed or controlled remotely
- CR3: Measure data instantaneously
- CR4: Emergency stop system
- CR5: Level the introducer and system to prevent kinking
- CR6: Force measurement equipment easy to replace
- CR7: Mechanism to prevent load cell damage
- CR8: Easy to disassemble/reassemble, transport case
- CR9: Force and distance calibrations and testing

Engineering Requirements

- ER1: Translation of catheter at least 2 ft
- ER2: Rotation of catheter at least 360 degrees
- ER3: Remote controlled from at least 10 ft away
- ER4: Sampling rate frequency between 5-30 Hz
- ER5: Handle catheter sizes between 2-15 French (1 F = 3 mm)
- ER6: Measure push resistance force between 0.1-10 N
- ER7: Measure displacement of catheter with resolution of at least 0.1 mm
- ER8: System noise/tolerance: ± 0.05 N
- ER9: Total size under 1 cubic foot
- ER10: Temperature below 60°C

Translate catheter over distance								
Full rotation of catheter	3							
Controlled from a distance	1							
Fast sampling rate		3	3					
Handle variable diameters		1						
Measure push resistance	1			3	1			
Measure displacement resolution	9			3				
Low system noise/tolerance			1	9		3	3	
Limited volume	1		1			1	1	

Table 1. House of quality correlations [2]

Table 2. House of quality [2]

Customer Needs	Customer Weights	Technical Requirements: Translate catheter	Full rotation of catheter	Controlled remotely	Fast sampling	Handle variable diameters	Measure push resistance	Measure displace-ment resolution	Low system noise	Limited volume	Moderate temperature	Customer Opinion Survey: 1 Poor	3	Acceptable	4	5 Excellent	Unsure
Translation and rotation of catheter	1	9	9	1	3	3		9	3		3			A		B C	
Pre-programmed or controlled remotely	1	3	3	9			1		3		3		A			B C	
Measure data instantaneously	3	1	1		9	1	3	3	9							A C	B
Emergency stop system	2			3					1					C		A	B
Level introducer and system to prevent kinking	3						9									A	B C
Force measurement equipment easy to replace	4						3			1				A			B C
Mechanism to prevent load cell damage	3				3		3		1						A		B C
Easy to disassemble/reassemble, transport case	5			1						9		A		C		B	
Force and distance calibrations and testing	3	3	3		1	3	3	3						C		A	B
Technical Requirement Units		ft	degree	ft	Hz	F	lbf	in	lbf	ft^3	°F	Legend	System name				
Technical Requirement Targets		2	360	10	5 to 30	2 to 15	0.0225-2.25	0.0034	0.0112	<1	<140	A	MSI interventional device testing equipment 3000				
Absolute Technical Importance		24	24	21	42	15	67	27	38	49	6	B	Microbot Medical: Liberty Robot				
Relative Technical Importance		1	2	3	8	4	7	6	9	10	5	C	Haptic Vision				

Benchmarking

- Autonomous Robotic Intracardiac Catheter Navigation Using Haptic Vision [3]
  - Controls
  - Force sensor
- Machine Solutions IDTE 3000 [4]
  - Servo rollers
  - Measurement controls
- Microbot Medical: Liberty Robot [5]
  - Remote
  - Portable

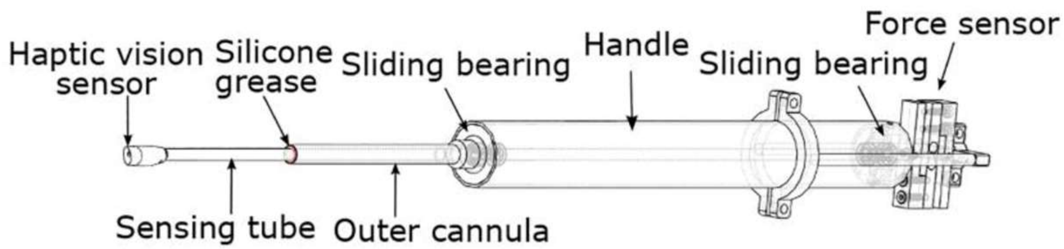


Figure 2. Haptic vision force sensor diagram [3]

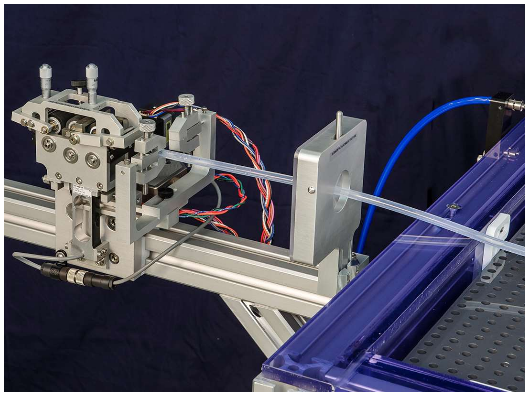


Figure 3. Machine Solutions IDTE [4]

Figure 4. Microbot Liberty device and controller [5]

Literature Review – Josh P.

LabVIEW Fundamentals [6]	Manual and tutorial on how to use LabVIEW, useful for programming
Machinery's Handbook (pg. 754-1003) [7]	Covers common material properties and testing methods, useful for material selection
Friction characteristics and servo control of a linear peristaltic actuator [8]	Discusses solution to non-linear pneumatics, useful if using pneumatics in design
Prevention of Servo-Induced Vibrations in Robotics [9]	Explains how to minimize vibrations in robotic systems, useful to reduce unnecessary motion
Software interfacing of servo motor with microcontroller [10]	Describes how to program a servo motor with MATLAB and a microcontroller, useful for programming motor controls
ISO 25539-1:2017 [11]	Standard that covers conditions for tests of endovascular devices
ViVitro Labs Catheter Testing and Delivery System Testing [12]	Provides examples of procedures for different catheter tests
The six factors you need to consider when picking a force sensor [13]	Lists important considerations of using a force sensor
ASTM-D2240-Durometer-Hardness [14]	Outlines testing definitions for rubber hardness, informs decision for rollers in contact with catheter
SAE J300 [15]	Standard for lubrication and engine oil, useful for bearing selection

Literature Review – Josh H.

Handbook to electric motors, 2nd ed. Chapter 2: types of motors and their characteristics [16]	Motors for special applications, stepper motor uses in different projects
NEMA standard for stepper motors [17]	Common standard pertaining to motor size and dimensions
Electromate stepper motor catalog [18]	Information on all motors using the NEMA standard, useful for determining best option for project
Selection of Microcontroller board and stepper motor driver for FDM 3D printing to reduce power consumption [19]	Discusses microcontrollers and drivers for stepper motors, informs choice of controller with power consumption
Handbook to electric motors, 2nd ed. Chapter 3: Motor Selection [20]	Standards of motors and applications
Tech tip: How to choose and use stepper motor power supply from automationDirect [21]	Online video with general guidelines for choosing an appropriate power supply, includes voltage and current information
Selecting the best power supply for your stepper motor or servo motor application [22]	Discusses different types of power supplies in technical detail, helpful for selection based on different applications
A design of the automatic anti-collision system [23]	Embedded systems design to help with anti-collision, useful for emergency stop function
Arduino tutorial: serial inputs [24]	Web article on serial inputs, how to set up, read, and provide inputs
Arduino interrupts tutorial [25]	Web article on interrupts of software or hardware for time-critical events

Literature Review – Gray

Theory and Design for Mechanical Measurements 7th Edition [26]	Measurements, uncertainties, and mechatronics of sensors, actuators, and controls, useful for obtaining accurate and required data
Shigley's Mechanical Engineering Design 11th Edition Chapter 19 [27]	Finite-element analysis of different geometries to find loads and torques to determine potential design components with high loads or torsion
Modeling and Estimation of Tip Contact Force for Steerable Ablation Catheters [28]	Analysis of catheter shaft curvature to determine contact force with catheter tip
Force Calibration for an Endovascular Robotic System with Proximal Force Measurement [29]	Indirect force measurement via motor transmission of forces to catheter tip
Accurate Estimation of Tip Force on Tendon-Driven Catheters Using Inverse Cosserat Rod Model [30]	Relationship between catheter curvature and contact force
ISO 10555-1:2023 [31]	Kink, torque, and tensile forces required for catheters, informs design requirements for components interacting with catheter
ZwickRoell Horizontal Testing of Catheter Systems [32]	Test machine for catheter coefficient of friction and breakaway torque, example of indirectly measured insertion force, track force, and lubricity
Nanoflex Robotics Advanced Magnetic Technology [33]	Use of magnetism to position and guide catheter tip through blood vessels, example of external robotic manipulation
Fatigue and Tribological Properties of Plastics and Elastomers [34]	Properties of plastics, polymers, and elastomers, formulae for hoop stress
LabVIEW Programming Reference Manual [35]	Detailed information on LabVIEW's different functions and references to allow communication between Arduino and LabVIEW via VISA functions

Column Deformation – Josh P.

$$P_{cr} = \frac{\pi^2 \frac{\pi(R^4 - r^4)}{64} E}{L^2}$$

$$= \frac{\pi^2 * \frac{\pi(1.5^4 - 1^4)(mm)^4}{64}\left(\frac{1\ m}{1000\ mm}\right)^4 * 2.6 * 10^8 Pa}{0.6096^2\ m^2}$$

$$= 0.0014\ N\ \ [36]$$

- Critical Load (P_{cr}): max load before deformation

$$X = C\sin\left(\sqrt{\frac{P}{EI}}Y\right) = 0.001m * \sin\left(\sqrt{\frac{P}{5.185*10^{-5}}}Y\right)\ [36]$$

- C = max deformation (tolerance between catheter and vein wall)

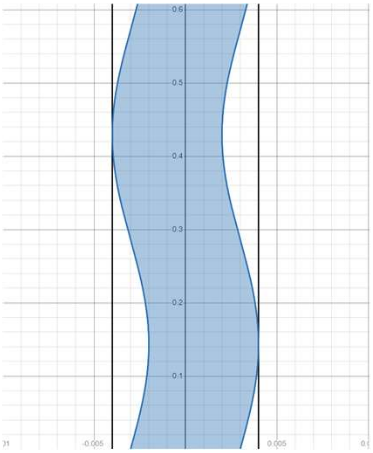


Figure 5. Deformation when P = 0.1N [37]

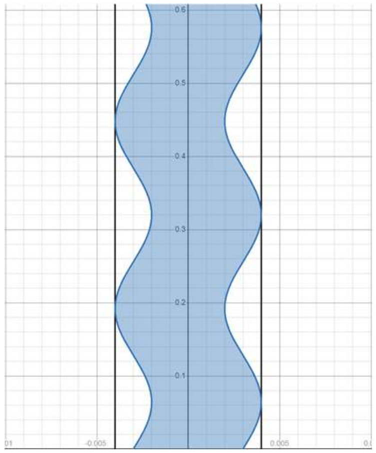


Figure 6. Deformation when P = 0.5 N [37]

Power Supply & Motors – Josh H.

$$S = r\frac{\pi}{180°}$$

- Translation Motor
  - NEMA 17 5:1 planetary gear with 25 mm drive roller
  - $\frac{0.39mm/step}{0.1mm/step} = 3.9{:}1$
  - 5:1 = 0.079 mm/step
- Rotation Motor
  - NEMA 11 with 30 mm drive roller
  - 128 sub step
  - 0.6 degrees/step

$$P = VI = (24V * 2A) * 2 = 96\ W$$

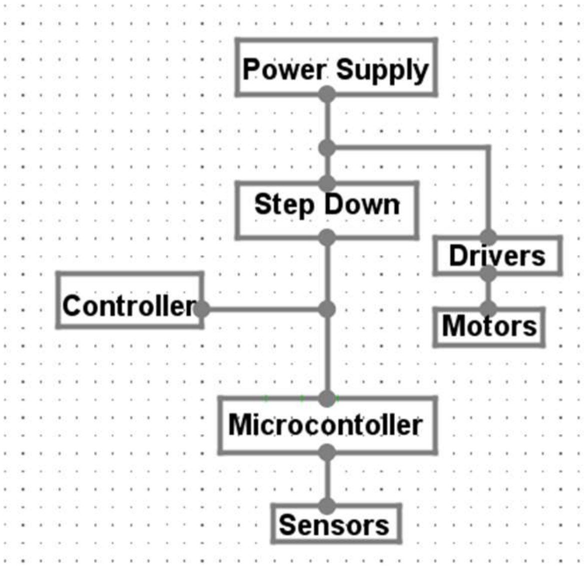
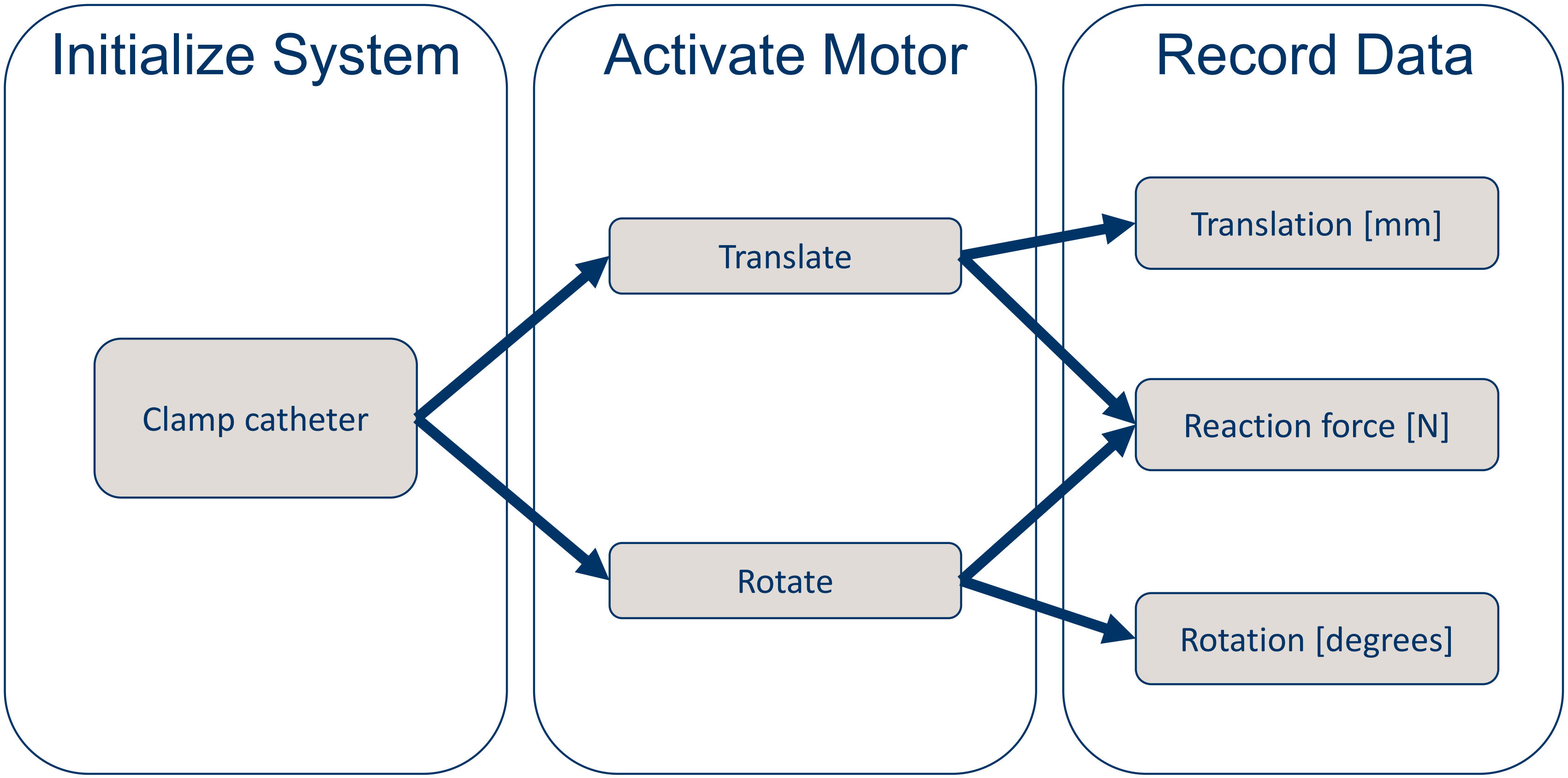


Figure 7. Power supply tree breakdown

Clamping Forces – Gray

- Finding cross-sectional area of undamaged, clamped catheter
  - Push force: $F_{fmax} = 10\ N$
  - Coefficient of friction (est. worst case): $\mu = 0.1$
  - $F_N = \frac{F_f}{\mu} = \frac{10\ N}{0.1} = 100\ N$
  - 55D Pebax: $\sigma_y = 12\ MPa$ [38]
  - $A_c = \frac{F}{\sigma} = \frac{100\ N}{12*10^6 Pa} = 8.33 * 10^{-6}\ m^2 = 8.33\ mm^2$
  - $d = 2 * \sqrt{\frac{A_c}{\pi}} = 2 * \sqrt{\frac{8.33\ mm^2}{\pi}} = 3.26\ mm \approx 10\ F$

Functional Decomposition



Concept Generation: Translation

Design A1

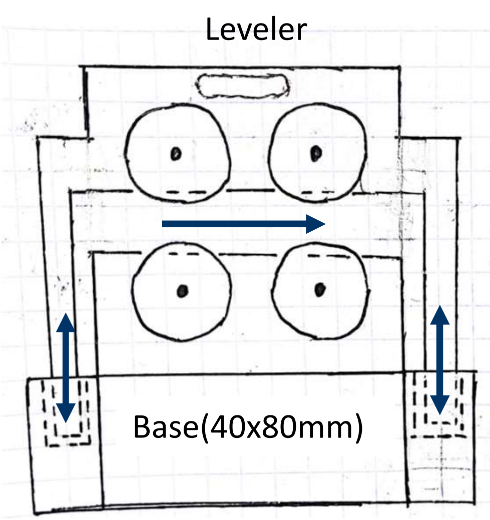


Figure 8. Design A - Front view

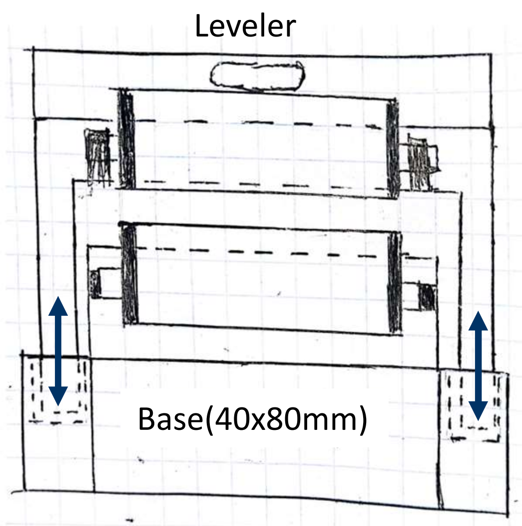


Figure 9. Design A - Side view

Design A2

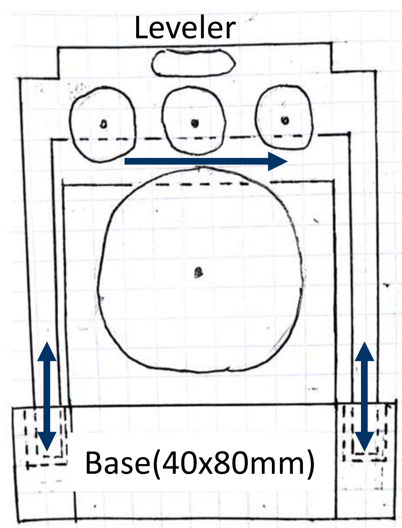


Figure 10. Design B – Front view

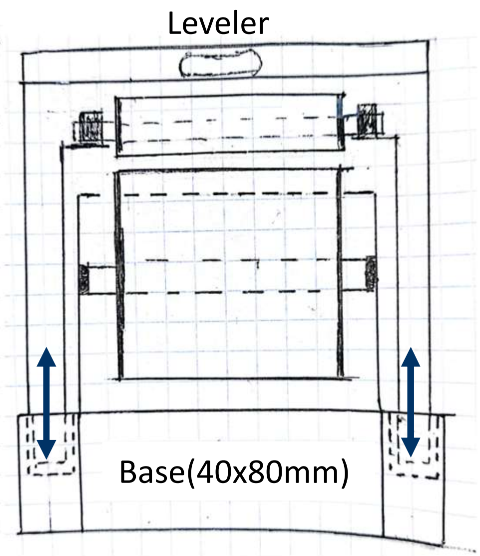


Figure 11. Design B – Side View

Concept Generation: Rotation

Design B1

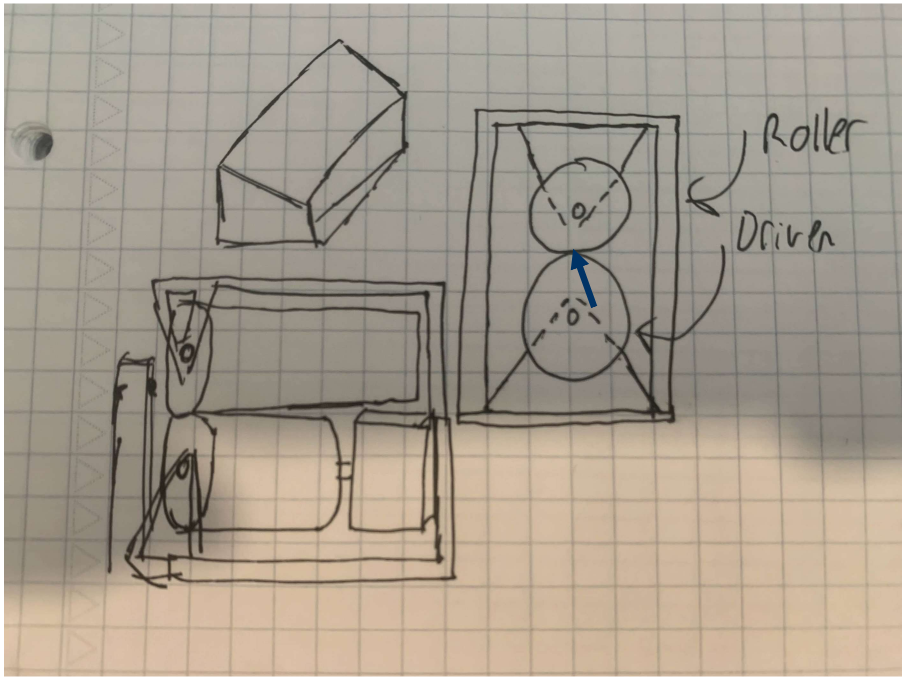


Figure 12. Roller Rotator

Design B2

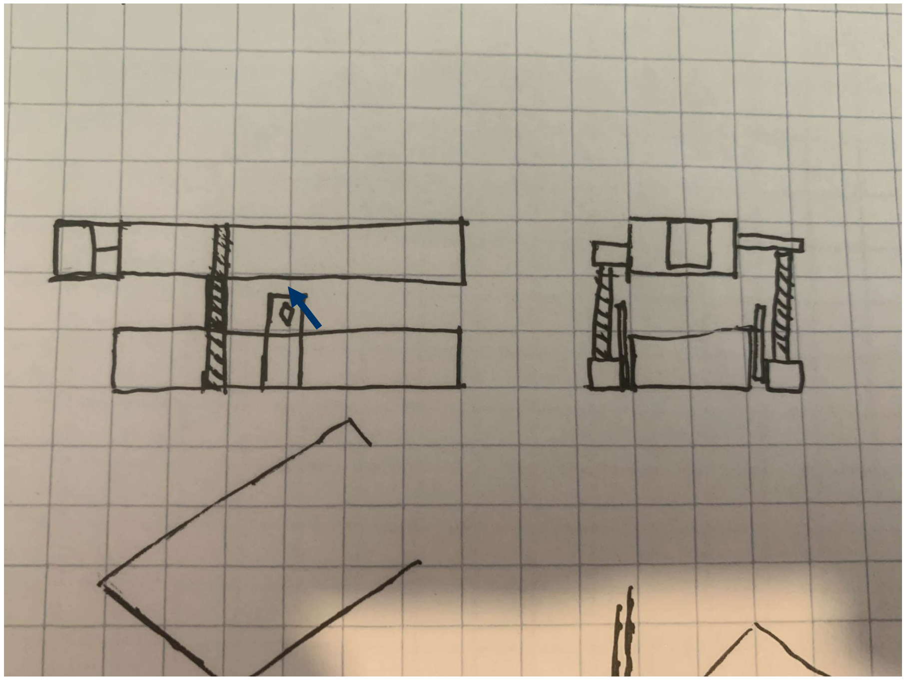


Figure 13. Friction plane rotator

Concept Generation: Sensors

Design C1

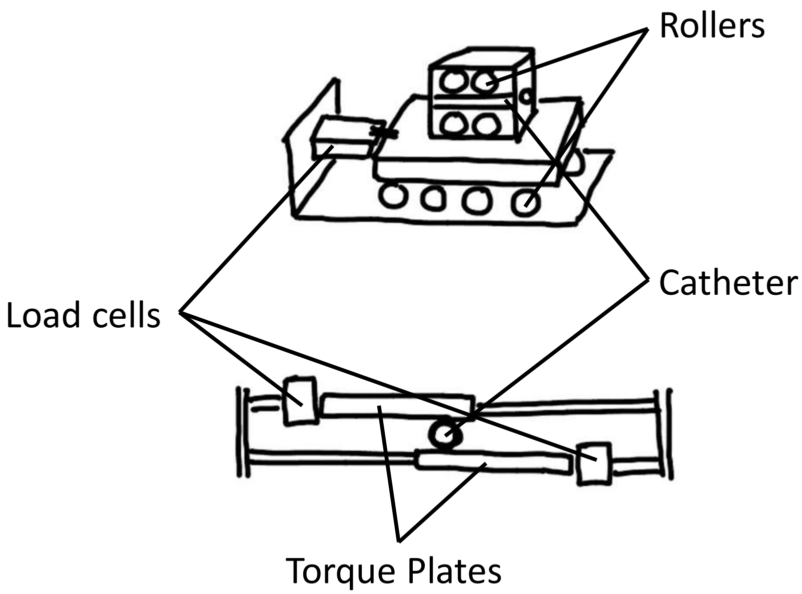


Figure 14. Load Cells for Translation and Rotation

Design C2

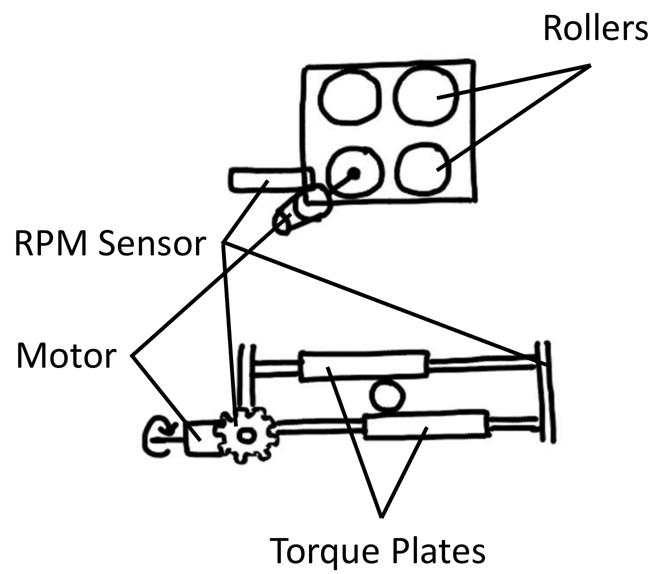
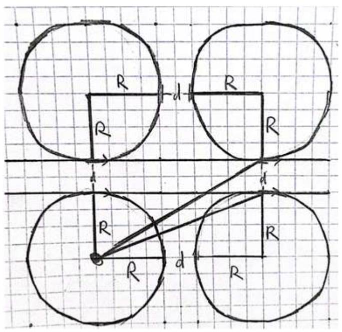
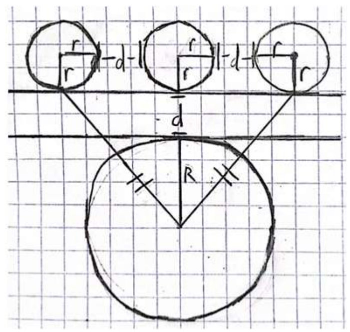


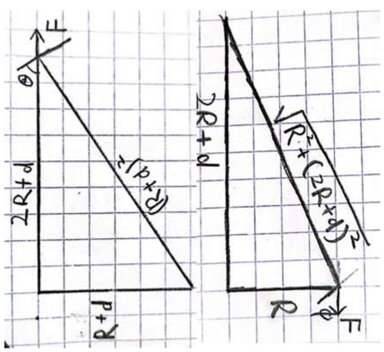
Figure 15. RPM Sensors for Translation and Rotation

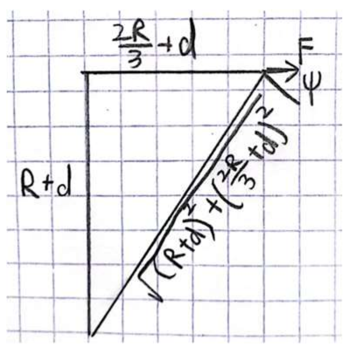
Engineering Calculations

- Translation



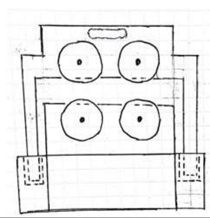
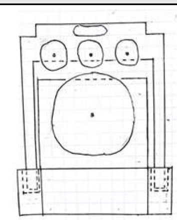
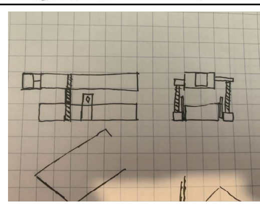
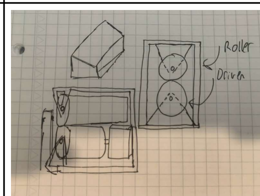
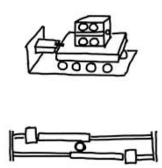
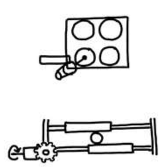






- Rotation
  - $l = d * \pi$
  - $I = \frac{1}{2} * M * r^2$
  - $I = \frac{1}{2} * p * \pi * r^4 * L$
  - $T = a * I$
- Sensors
  - $P = VI = Fv$
  - $v = r\omega$
  - $F = \frac{VI}{r\omega}$
  - $\tau = F \times r$
  - $\tau = \frac{VI}{\omega}$

Concept Selection

Subsystems	1	2
A. Translation		
B. Rotation		
C. Sensors		

- Translation: A1
- Rotation: B2
- Sensors: C1 (reworked)

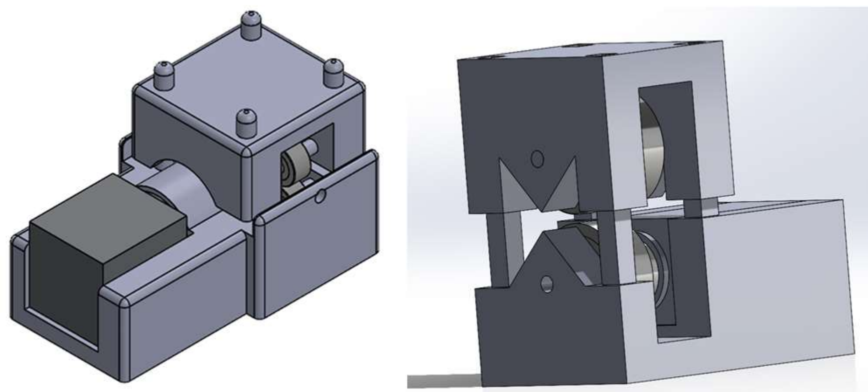


Figure 16. Translation (left) and rotation (right) CAD

Schedule

TASK	ASSIGNED TO	PROGRESS	START	END
Course Deliverables (Fall 2024)				
Presentation 1 Slides	All	100%	9/9/24	9/13/24
Presentation 1 Practice	All	100%	9/13/24	9/15/24
Presentation 1 Revisions	All	100%	9/16/24	9/18/24
Presentation 2 Slides	All	100%	9/26/24	10/3/24
Presentation 2 Practice	All	100%	10/4/24	10/6/24
Presentation 2 Revisions	All	100%	10/7/24	10/9/24
Report 1	All	100%	10/4/24	10/20/24
Website Development 1	All	100%	10/17/24	10/24/24
Analytical Analysis Memo	All	100%	10/18/24	11/1/24
Presentation 3 Slides	All	100%	10/24/24	10/31/24
Presentation 3 Practice	All	100%	11/1/24	11/3/24
Presentation 3 Revisions	All	100%	11/4/24	11/6/24
Prototype 1 Demo	All	100%	10/19/24	11/15/24
Report 2	All	100%	11/12/24	11/26/24
Final CAD	All	100%	11/18/24	12/2/24
Final BOM	All	100%	11/18/24	12/2/24
Prototype 2 Demo	All	100%	11/10/24	12/1/24
Project Management	All	100%	11/25/24	12/5/24
Website Development 2	All	100%	11/29/24	12/6/24

TASK	ASSIGNED TO	PROGRESS	START	END
Course Deliverables (Fall 2024)				
Project Management	All	100%	1/13/25	1/17/25
Gantt chart/WBS	Gray	100%	1/13/25	1/17/25
BOM	Josh H.	100%	1/13/25	1/17/25
Manufacturing	Josh P.	100%	1/13/25	1/17/25
Engineering Calculations Summary	All	100%	1/20/25	1/24/25
Self-Learning/Individual Analysis	Individual	100%	1/20/25	2/16/25
Hardware Status Update - 33%	**All**	**100%**	**1/13/25**	**2/5/25**
Wiring System	Josh H.	100%	1/13/25	2/2/25
Sensors CAD design	Gray	100%	1/13/25	1/24/25
Website Check 1	Josh P.	100%	2/14/25	2/21/25
Hardware Status Update - 67%	**All**	**100%**	**2/6/25**	**2/26/25**
Translation System (shafts, sleeves, and housing)	Josh P.	100%	1/13/25	2/23/25
Motor Mount and Load Cells System	Gray	100%	1/13/25	2/23/25
UGRADS Registration	Gray	100%	2/20/25	3/6/25
Finalized Testing Plan	Gray	100%	2/24/25	3/21/25
Hardware Status Update - 100%	**All**	**100%**	**2/27/25**	**3/26/25**
Rotation System (shafts, sleeves, and housing)	Josh P.	100%	1/13/25	3/23/25
Frame System	All	100%	2/27/25	3/23/25
Arduino Code	Josh H.	100%	1/13/25	3/23/25
Electronics Box	Gray	100%	2/27/25	3/23/25
UGRADS Poster Draft	All	100%	3/8/25	3/28/25
Initial Testing Results	All	100%	3/21/25	4/9/25
UGRADS Final Poster and Presentation	All	100%	3/17/25	4/11/25
Final CAD Packet	All	100%	3/17/25	4/13/25
Product Demonstration	All	100%	4/2/25	4/16/25
Final Testing Results	All	100%	4/9/25	4/16/25
Final Report	All	100%	4/4/25	4/18/25
Website Check 2	All	100%	4/12/25	4/19/25
UGRAD Symposium	All	50%	4/25/25	4/25/25
Spec Sheet/Operation Manual	All	0%	4/16/25	4/30/25
Client Handoff	All	0%	4/28/25	5/2/25

Budget

Income			
From Sponsor			$5,000
From Fundraising	$500	Current:	$350.00
Total:			$5,350

Expenses		
Order Number	Description	Cost
Order 1	Idle and driver rollers for translation	$110.96
Order 2	NEMA 17 stepper with gear ratio 5:1	$43.84
Order 3	NEMA 11 stepper motor	$26.31
Order 4	driver roller 25mm	$43.84
Order 5	Stepper motor drivers	$27.13
Order 6	30mm driver roller	$74.89
Order 7	Translation 3D print 1	$39.40
Order 8	Rotation 3D print 1	$18.44
Order 9	Nema 17 back 3D print 1	$34.64
Order 10	Nema 17 back 3D print 2	$30.24
Order 11	Nema 11 back 3D print 1	$26.06
Order 12	Translation 3D print 2	$21.20
Order 13	Translation special 3D print 1	$116.58
Order 14	Translation 3D print 3	$55.28
Order 15	Shafts, frames, load cells	$108.60
Order 16	Screws and USB	$26.08
Order 17	Bearings and snap rings	$21.12
Order 18	Arduino and electronics	$186.76
Order 19	Screw terminals and H bridges	$18.54
Order 20	Idler roller	$25.30
Order 21	Rotation 3D print 2	$23.24
Order 22	Translation special 3D print 2	$137.64
Order 23	Sensor parts final	$30.79
Order 24	Electrical box print 1	$50.96
Order 25	Electrical box print 2	$92.00
Order 26	Rotation motor angling	$342.02
Total Expenses:		$1,731.86
Budget Left:		$3,618
Percent used:		32.37%

Design Validation

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Motor	water ingress	stop operation, electrical hazard	environmental conditions	40	shield component
Motor	high-cycle fatigue	stop operation	material/component issues, fatigue	42	replace component every 5 years
Roller	fretting wear	misalignment	material/component issues, tolerances	24	replace component every 5 years
Roller	surface fatigue wear	slipping	material/component issues, fatigue	24	replace component every 5 years
Shaft	high-cycle fatigue	fracture	material/component issues, cracking	42	replace component every 5 years
Sensor	water ingress	emergency stop disabled	environmental conditions	40	shield component
Remote Control	connection loss	stop operation	environmental conditions	140	ensure stable connection conditions
Torque Plate	fretting wear	misalignment	material/component issues, tolerances	24	replace component every 5 years
Torque Plate	surface fatigue wear	slipping	material/component issues, fatigue	24	replace component every 5 years
Lead Screw	fretting wear	misalignment	material/component issues, tolerances	24	replace component every 5 years
Lead Screw	high-cycle fatigue	fracture	material/component issues, cracking	42	replace component every 5 years

Prototyping

- Prototype 1
  - Initial translation system test

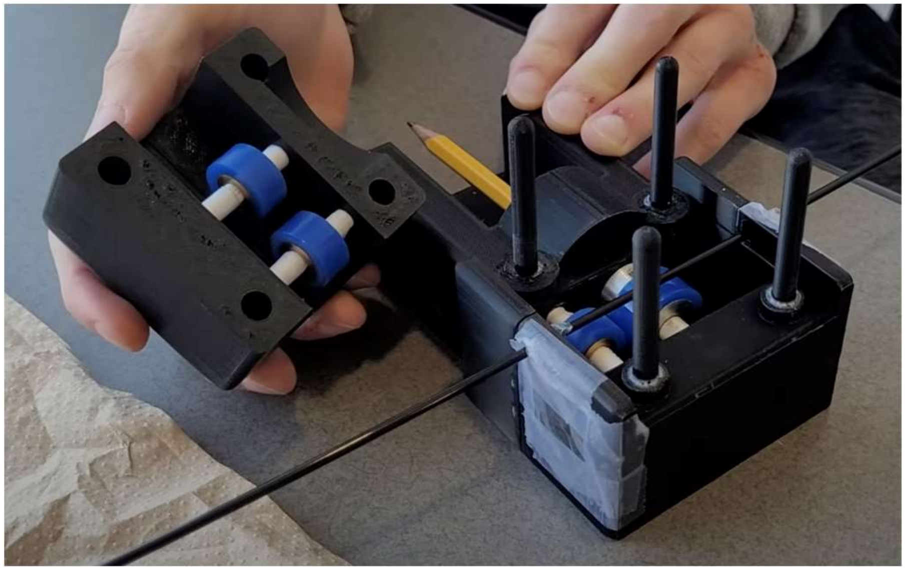


Figure 17. First translation prototype

- Prototype 2
  - Arduino stepper motors test

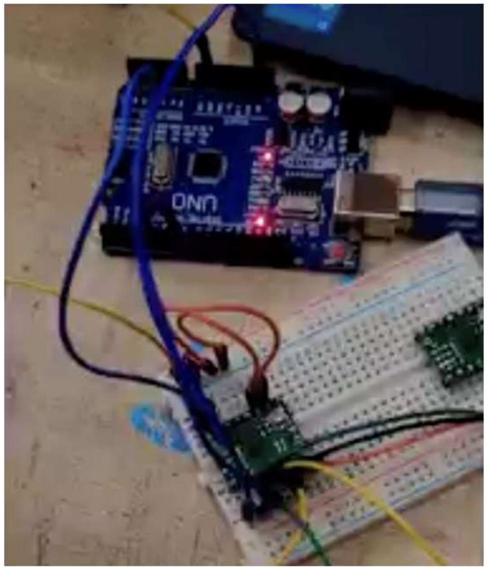


Figure 18. Wired stepper motor driver

Final Hardware

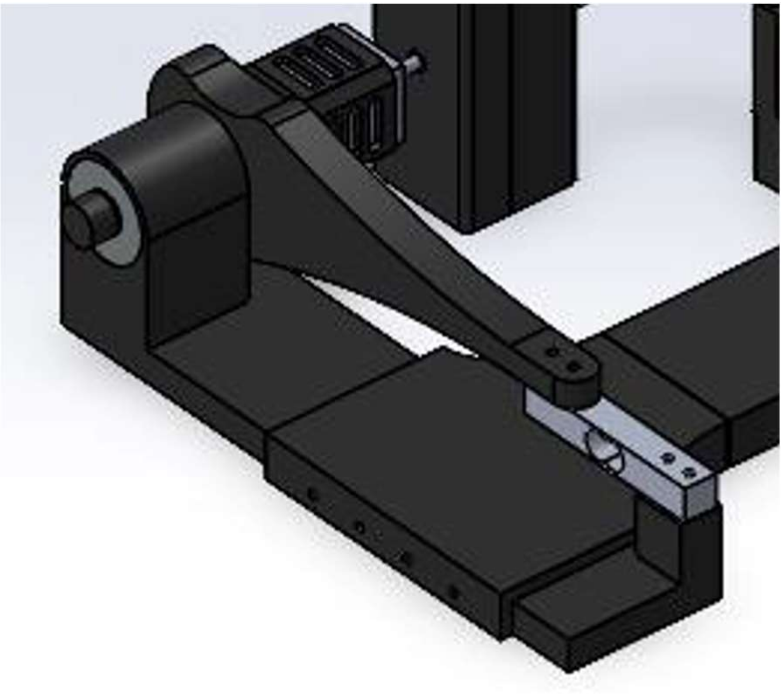


Figure 19. Final CAD

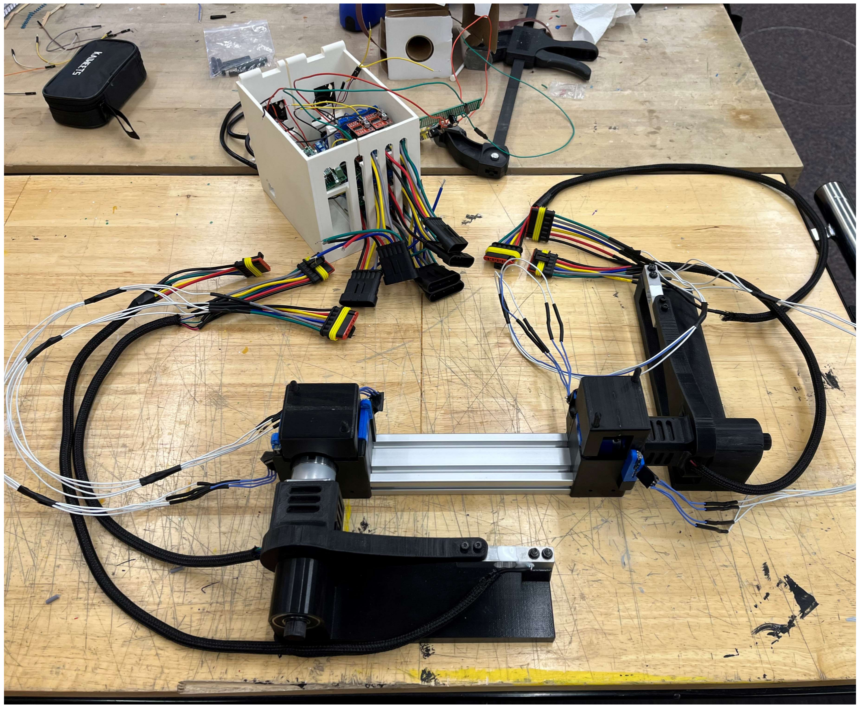


Figure 20. 100% hardware assembly

Testing Plan

Experiment	Relevant DRs	Testing Equipment	Other Resources
EXP1 - Motion Test	CR1, ER1, ER2	Arduino code Measuring tape Protractor	Catheter
EXP 2 - Remote Control Test	CR2, CR4, ER3	Arduino code Computer Measuring tape Stopwatch	Catheter
EXP 3 - Calibration Test	CR9, ER8	Arduino code Computer Weights	Load cells (partially removed from system)
EXP 4 - Data Collection Test	CR3, ER4, ER6, ER7	Arduino code Computer	Catheter
EXP 5 - Level/Bending Test	CR5	Level Protractor	Catheter
EXP 6 - Assembly Test	CR6, CR8, ER9	Measuring tape Stopwatch	Lab space
EXP 7 - Water Resistance Test	CR7	Voltmeter	Water
EXP 8 - Lead Screws Test	ER5	Arduino code Calipers	Multiple catheters
EXP 9 - Heat Test	ER10	Arduino code Temperature gun	Room-temperature environment

Specification Sheet: CRs

Customer Requirement	CR met? (✓ or X)	Client Acceptable (✓ or X)
CR1 – Catheter motion	✓	✓
CR2 – Remote control	✓	✓
CR3 – Instant data	✓	✓
CR4 – Emergency stop	✓	✓
CR5 – Prevent kinking	✓	✓
CR6 – Replaceable	✓	✓
CR7 – Prevent damage	✓	✓
CR8 – Assembly	✓	✓
CR9 – Calibrations	✓	✓

Specification Sheet: ERs

Engineering Requirements	Target	Tolerance	Measured/Calculated Value	ER met? (✓ or X)	Client Acceptable (✓ or X)
ER1 - Translation	2ft	±4in	2ft	✓	✓
ER2 - Rotation	360°	±10°	360°	✓	✓
ER3 - Remote	10ft	±4in	20ft	✓	✓
ER4 - Frequency	5-30Hz	±1Hz	30Hz	✓	✓
ER5 - Catheter size	2-15F	±1F	0-24F	✓	✓
ER6 - Forces	0.1-10N	±0.01N	0.1-10N	✓	✓
ER7 - Displacement	0.1mm	±0.01mm	0.1mm	✓	✓
ER8 - Tolerance	0.05N	±0.01N	0.05N	✓	✓
ER9 - Size	$1ft^3$	$\pm 0.1ft^3$	$1.2ft^3$	X	✓
ER10 - Temperature	60°C	±5°C	38°C	✓	✓

Discussion

- Success Metrics
  - Catheter moves and rotates
  - Control process comparable to hand-guided catheter
- Future Work
  - Standardized medical device testing
  - Move from benchtop models to clinical settings
  - Remote operation on patients

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Thank you

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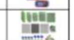
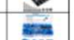
Purchased Parts

Part	Details	Status	Link	Supplier	Price per Unit	Quantity	Total Price	Picture
Translation Idler Roller	3/4in roller	Delivered	https://www.mcm	Mc-MasterCarr	$20.73	3	$62.19	
Translation Driver Roller	25mm roller	Delivered	https://www.mcm	Mc-MasterCarr	$31.81	1	$31.81	
Rotation Driver Roller	30mm roller	Delivered	https://www.mcm	Mc-MasterCarr	$31.93	1	$31.93	
Translation Stepper Motor	NEMA 17 with 5:1 gear ratio	Delivered	https://www.ama	Amazon	$40.15	1	$40.15	
Rotation Stepper Motor	NEMA 11	Delivered	https://www.ama	Amazon	$24.10	1	$24.10	
Motor Driver	DVR8483 stepper motor driver	Delivered	https://www.polol	Pololu	$9.95	4	$39.80	
Arduino Mega	Arduino Mega 2560 REV3	Delivered	https://www.ama	Amazon	$52.34	1	$52.34	
Arduino Mega terminal block sheild	screw terminal block breakout module for Arduino Mega	Delivered	https://www.ama	Amazon	$32.37	1	$32.37	
Arduino basic starter kit	Arduino basic starter kit LEDs, resistors, buttons, capacitors, transistors, diodes, wires, breadboard, power supply	Delivered	https://www.ama	Amazon	$10.81	1	$10.81	
5V mini fan	4pcs 30mm 5V fans	Delivered	https://www.ama	Amazon	$10.81	1	$10.81	
DC 12V relay module	4pcs DC 12V relay module	Delivered	https://www.ama	Amazon	$7.57	1	$7.57	
PCB board kit	82 pcs PCB board kit with connectors	Delivered	https://www.ama	Amazon	$12.98	1	$12.98	
22 gauge wire	33ft/10m wire	Delivered	https://www.ama	Amazon	$14.06	1	$14.06	
Micro lead screw	4mm 5V 2-phase 4-wire stepper motor micro lead screw	Delivered	https://www.ama	Amazon	$5.92	4	$23.68	
Load cell kit	4 sets 1kg load cells and HX711 boards	Delivered	https://www.ama	Amazon	$15.49	1	$15.49	
Roller Shafts	4.5in x 1/4in stainless steel shaft	Delivered	https://www.mcm	Mc-MasterCarr	$6.86	2	$13.72	
T-slotted frame	1ft T-slotted framing rail	Delivered	https://www.mcm	Mc-MasterCarr	$7.57	1	$7.57	
Idler Roller	1 1/2in roller	Delivered	https://www.mcm	Mc-MasterCarr	$55.77	1	$55.77	
Load cell bearings	4pcs 15x35x11mm deep groove ball bearings	Delivered	https://www.ama	Amazon	$8.33	1	$8.33	
Snap rings	145pcs external retaining rings 15-28mm	Delivered	https://www.ama	Amazon	$12.79	1	$12.79	
H bridges	4pcs mini L298N 2 channel H bridge DC motor driver board with MX1508 chip	Delivered	https://www.ama	Amazon	$7.99	1	$7.99	
USB cable	USB cable type A male to B male, 20ft	Delivered	https://www.ama	Amazon	$13.99	1	$13.99	
M4 screw kit	300pcs M4 hex socket head cap screw assortment with nuts and washers, 6, 8, 10, 12, 16, 20, 25, 30mm (black)	Delivered	https://www.ama	Amazon	$8.99	1	$8.99	
PCB terminal block connectors	70pcs 2 pin & 3 pin 5mm/0.2inch pitch PCB mount screw terminal block connector	Delivered	https://www.ama	Amazon	$8.99	1	$8.99	
Precision Single U-Joint	Pin and Block Joint, for 1/4" Diameter x 5/8" Deep Shaft, Acetal	Delivered	https://www.mcm	Mc-MasterCarr	$40.07	4	$160.28	
Stainless Steel Ball Bearing	Shielded, Trade Number R168-2Z	Delivered	https://www.mcm	Mc-MasterCarr	$5.72	8	$45.76	
Rotary Shaft	303 Stainless Steel, 1/4" Diameter, 9" Long	Delivered	https://www.mcm	Mc-MasterCarr	$10.73	2	$21.46	
Press-Fit Low-Profile Drive Roller	1-1/4" Roller Diameter, 3/4" Roller Width	Delivered	https://www.mcm	Mc-MasterCarr	$28.96	1	$28.96	
Metal Gear - 20 Degree Pressure Angle	Round Bore with Set Screw, 48 Pitch, 48 Teeth	Delivered	https://www.mcm	Mc-MasterCarr	$28.52	3	$85.56	

Manufactured Parts

Part	Details	Status	Manufacturer	Lead Time (hours)	Material	Components	Manufacturing Location	Price per Unit	Quantity	Total Price
Prototype Translation Housing	Translation Housing	Complete	Josh P.	15	3D-printed PLA	1	Cline Library	$39.40	1	$39.40
Prototype Rotation Housing	Rotation Housing	Complete	Josh H.	10	3D-printed PLA	1	Cline Library	$18.44	1	$18.44
Shafts (metal)	Metal shafts for bearings	Complete	Josh P.	1	Stainless Steel	6	Engineering Machine Shop	$0.00	6	$0.00
Prototype mount for back of NEMA17	load cell housing	Complete	Josh P.	12	3D-printed PLA	4	Cline Library	$34.64	1	$34.64
Mount for back of NEMA17	load cell housing	Complete	Josh P.	28	3D-printed PLA	4	Cline Library	$30.24	1	$30.24
Mount for back of NEMA11	load cell housing	Complete	Josh P.	28	3D-printed PLA	4	Cline Library	$26.06	1	$26.06
Electronic Wiring	Circuit board wiring	Complete	All	20	Wires, solder	5	Cline Library	$0.00	1	$0.00
Prototype 2 Translation Housing	Translation Housing	Complete	Josh P.	10	3D-printed PLA	18	Cline Library	$21.20	1	$21.20
Translation Prototype Special Components	Small components or different material	Complete	Josh P.	1	Vero and Agilus	14	Bioengineering Devices Lab	$116.58	1	$116.58
Translation Final Housing	Translation Final Housing	Complete	Josh P.	22	3D-printed PLA	15	Cline Library	$55.28	1	$55.28
Rotation Final Housing	Rotation Final Housing	Complete	Josh P.	10	3D-printed PLA	12	Cline Library	$52.48	1	$52.48
Translation Final Special Components	Small components or different material	Complete	Josh P.	1	Vero and Agilus	10	Bioengineering Devices Lab	$137.64	1	$137.64
Sensor Parts Final	load cell housing	Complete	Josh P.	19.5	3D-printed PLA	8	Cline Library	$60.04	1	$60.04
Electronic Box Prototype	electronics housing	Complete	Josh P.	28	3D-printed PLA	4	Cline Library	$50.96	1	$50.96
Electronic Box Final	electronics housing	Complete	Gray	37	3D-printed PLA	4	Cline Library	$82.76	1	$82.76
Box Lid Reprint	electronics lid	Complete	Gray	4	3D-printed PLA	2	Cline Library	$9.24	1	$9.24